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ABSTRACT

Recent attempts to match shortwave albedo of snow for clear skies using approximate spectral solar fluxes and solutions of the radiative transfer equation for snow were unsuccessful until a separate surface reflection term was introduced. A separate consideration of specular reflection from surface snow grains has been objected to as being ad hoc. I discuss results based on a new parameterization of shortwave radiation. Compared to the previous radiation models, the new model gives higher diffuse insolation and predicts higher albedos. The difference between observed and predicted albedos is substantially reduced without invoking surface reflection.

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The shortwave albedo of snow for clear skies was calculated by Barkstrom (1972) using a solution of the radiative transfer equation for a plane-parallel 'atmosphere' model of snow. In this model ice grains on the surface of snow scatter radiation the same way as the grains deep within. By showing good agreement with observations (Liljequist, 1956; Rusin, 1964) he questioned ad hoc surface reflectivity introduced by Liljequist (1956). Recently, Wiscombe and Warren (1980) also have argued against this reflectivity.

There were two shortcomings in Barkstrom's calculation: (1) the diffuse shortwave radiation, whose magnitude relative to direct radiation increases as the solar elevation decreases, was ignored, and (2) the albedos were not calculated in terms of snow grain size, but by adjusting a parameter in the radiative transfer equation, called the single scattering albedo. Calculations of Wiscombe and Warren (1980) suffer the latter shortcoming.

To remove these shortcomings, the albedos were calculated in terms of snow grain size using parameterized models for spectral solar fluxes and approximate solutions of the radiative transfer equation (Choudhury, 1981; Choudhury and Chang, 1981a, b). For a plane-parallel 'atmosphere' model of snow, the calculated albedos were lower than the observations, and the difference increased with decreasing solar elevation (see Choudhury, 1981; Choudhury and Chang, 1981b). To match observations the surface reflectivity was reintroduced. It was, however, cautioned that the failure to match observations without a separate surface reflectivity could be due to inaccuracies in the models. This note gives albedo results based on a new parameterization of incident solar radiation.

The diffuse radiation models used previously were based upon the graphical method suggested by Robinson (1966), which is to use an empirical equation for the radiation on a surface with albedo 0.25, and correct it for the actual surface albedo using his graphs for varied solar elevations, atmospheric precipitable water and turbidity. The fact that snow is more reflective in the visible than in near infrared was not used in these models. One would expect that atmospheric backscattering contribution depends upon spectral surface albedo.

Sivkov (1971) suggests that instead of calculating the diffuse radiation for varied surface albedos, the total radiation be calculated from the equation

$$Q = \frac{4 + 3(1 - g)\tau}{4 + 3(1 - g)(1 - A)\tau} \cdot Q_0$$

where g is the effective asymmetry factor for atmospheric scattering phase function (Sobolev, 1975 and Mo et al., 1975), τ is the sum of optical thicknesses for Rayleigh and aerosol scatterings (Leckner, 1978), A is diffuse albedo of the surface (Choudhury and Chang, 1979) and Q_0 is the total radiation on a black surface (Leckner, 1978 and Dozier, 1980). The advantage of this parameterization over the Robinson's is that spectral surface albedos can be inputed directly into the model. The coefficient for Q_0 can be shown to be the atmospheric backscattering contribution to total radiation in the delta-Eddington approximation (Joseph et al., 1976) of the radiative transfer equation.

The overall accuracy of the radiation models may be assessed by comparing with observed insolations. This comparison is shown in Figure 1 for atmospheric parameters representative of Mirny and Maudheim (Antarctic coastal stations): precipitable water 0.25 cm, Angstrom turbidity 0.01, ozone 0.35 cm, surface pressure 980 mb and snow grain size 0.3 mm. The model for direct radiation is identical to the previous models (see Choudhury and Chang, 1981a), and the calculated insolations are about 4% lower than the observations at high elevations. The present model, however, gives better results for diffuse insolations. The key factor in this improvement appears to be the inclusion of spectral snow albedo in calculating the atmospheric backscattering contribution. It is to be noted that both direct and diffuse insolations now agree with the observations at low solar elevations where the observed albedos were found to differ most from the calculations.

New albedos, together with those obtained using Choudhury and Chang's (1981b) radiation model, are shown in Figure 2. The surface reflection is ignored. The present radiation model gives higher diffuse insolations, and predicts higher albedos. The difference between the observed and predicted albedos is reduced, but at low elevations the albedos are still underestimated by a few percent. Whereas the calculated albedos change very little at low elevations, the observed albedos change rapidly. Rusin (1964) also observed such variations. Approximate models should not be used to authenticate or discredit these observations. But, it appears unlikely that these variations are observational errors associated with measuring low incident fluxes. The present radiation model agrees with the observed fluxes, at least for low elevations. If surface glint is *ad hoc* and should be excluded from these calculations then further investigation of the accuracy of the delta-Eddington solution (Joseph et al., 1976) for snow at low solar elevations is needed to clarify these discrepancies.

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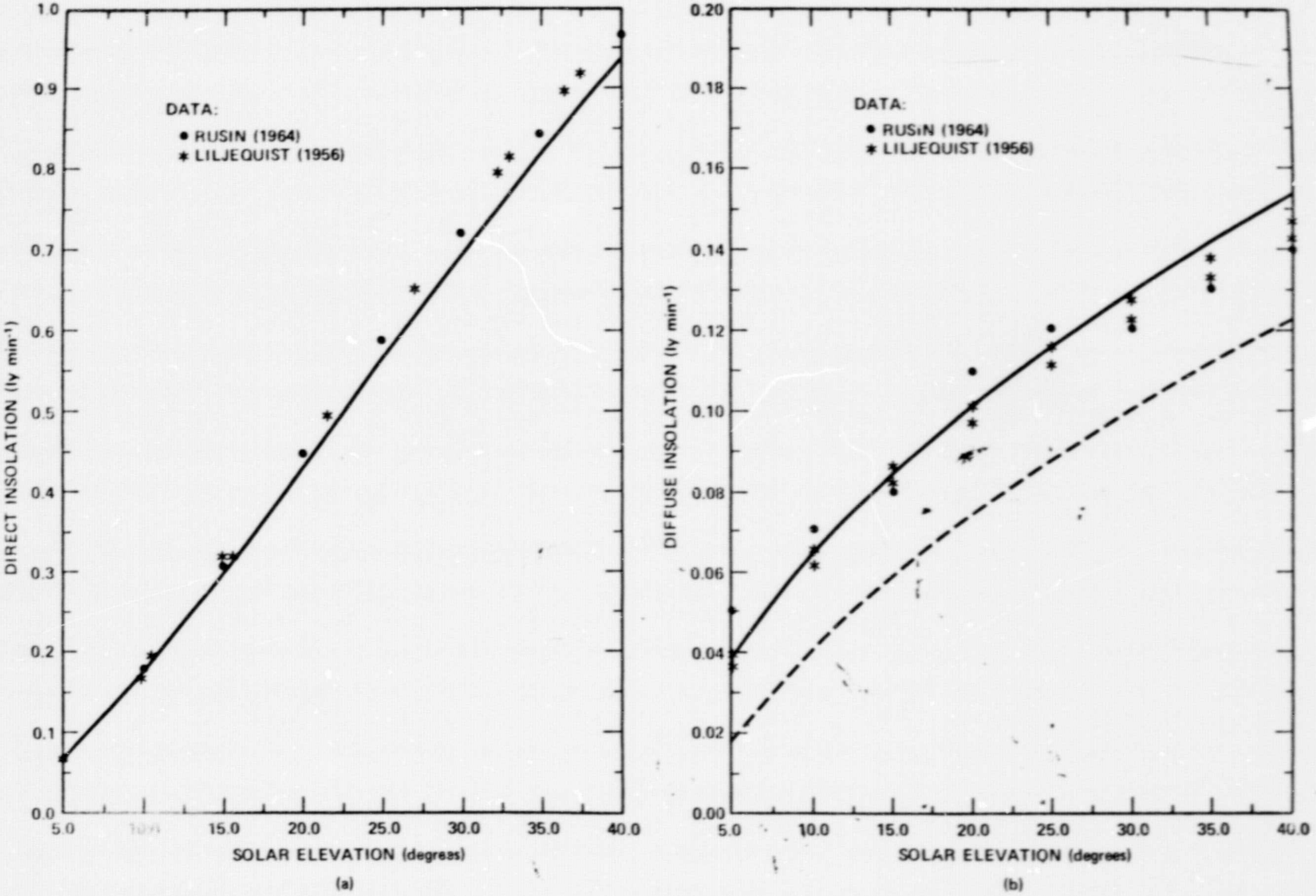

Figure 1. Comparison of calculated and observed insolations, (a) direct insolation, (b) diffuse insolation. The solid line using the present model, the dashed line using Choudhury and Chang's (1981b) radiation model.

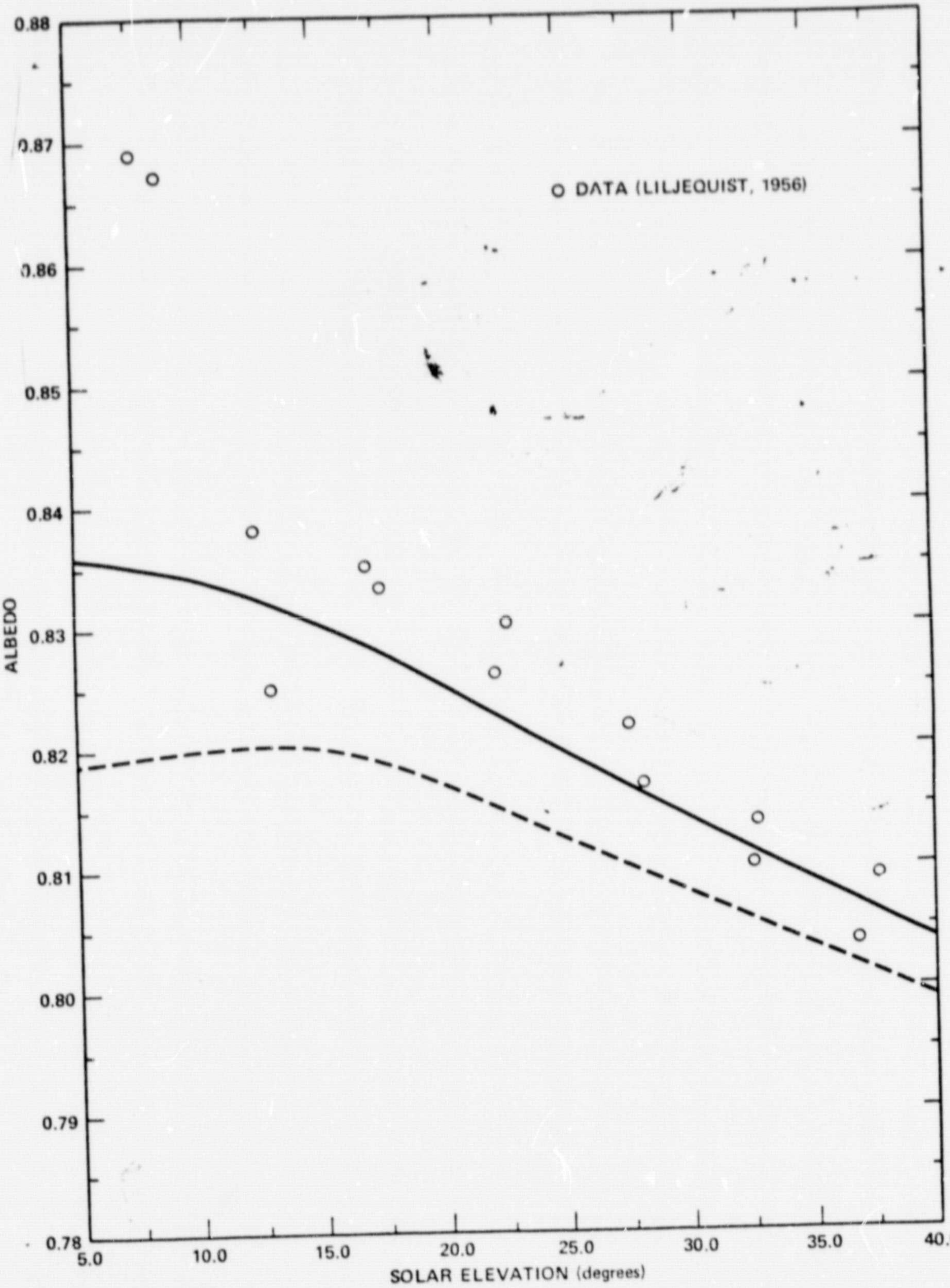

Figure 2. Comparison of observed and calculated albedos. The lines have the same meaning as in Figure 1b. Note the discrepancy with observations at elevation 7.5°.